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Gesture Recognition & Haptic Feedback Technologies

A whitepaper on touchless interfaces and tactile feedback

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Overview

This whitepaper explores the reasons for, and enabling technologies behind, gesture recognition and haptic feedback markets and highlights the advantages and limitations of a variety of implementations.

Since the development of the trackball in 1941, which later led to the consumer release of the computer mouse in the 1980's, engineers across the globe have sought to push the limitations of computer-human interaction in an attempt to achieve a more intuitive, natural user experience. The expressive world of gestures, used in day-to-day, face-to-face communications for millennia have been an obvious avenue to explore, pared with sophisticated audio and visual developments, the market has come a long way. The importance of the human sense of touch has also been championed, with 'haptic feedback' being added to many consumer devices. But until now, the two markets have not merged.

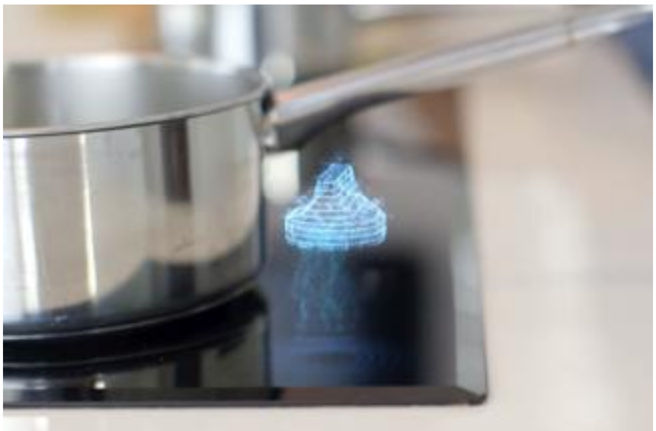
Feeling without Touching

Computers have come a long way in 'understanding' humans. Controlling them with human gestures is now commonplace: swiping, pinching, pushing virtual buttons and typing on touch screens is available in almost every type of electronic equipment. Almost all demand ***touching*** the physical controls or surfaces, but this has limitations. Simple wear and tear of electrical switches and their vulnerability to contamination (e.g. coffee in the computer keyboard) are well-known examples. Less obvious examples include the possibility of cross-infection from medical equipment controls[1], public toilets, and elevators; or possible injury from hot or cold surfaces, sharp or electrically charged objects.

In the last few years controlling machines by human gestures ***without touching*** them has become an area of intense interest to major technology companies such as Microsoft,[2] Intel[3] and Google[4]. This is driven, in large part, by the huge demand to detect body movements at a distance for the enormous global gaming market.[5] But more generally ***touchless*** gesture recognition is acknowledged as the 'next frontier' in human machine interfaces for an enormous range of applications, which are now moving beyond computer and game interfaces to include consumer and domestic appliances, and automotive dashboards.

Users of ***touchless*** controls often comment they lack precision and the ***tactile feedback*** humans find so valuable in confirming they are engaging with the electronics. Naturally we prefer feeling a control, different textures and surfaces, and often hearing an audible confirmation too. So effective simulation of tactile feedback, ***haptics***, is seen as the key to unlocking the potential of ***touchless*** gesture recognition.

A Feel for the Market



Touchless haptic hob control

The global market for gesture recognition will exceed $12.7Bn in 2020, driven by expanding applications in gaming, healthcare, automation, consumer electronics and automotive sectors[6]. Consumer electronics (including gaming) currently accounts for ~99% of the gesture recognition market. But more companies are bringing products to market using these technologies. For example, in 2015 the automotive market adopted the technology through BMW's introduction of touchless gesture control of

1 Gestsure & Microsoft Kinect
2 Microsoft Kinect
3 Intel Perceptual Computing Initiative
4 Google Project Soli

5 Microsoft Kinect (debut)
6 Gesture recognition market trends

the infotainment system in the new 7 series saloon[7]. For both gesture recognition and touchless sensing technologies the market will grow at an explosive rate (28% CAGR) between now and 2020, when it will be worth $24Bn worldwide[8].

Gesture Recognition Techniques

3D hand position and gesture recognition

Most systems detecting human gestures describe the body as virtual objects in a 3D coordinate system. Detecting the relationship between points and their relative motion provides the gesture recognition. The resolution of the input determines how accurately the position and orientation of the points representing hands or fingers, for example, is known.

Real time 3D hand tracking

7 BMW gesture control
8 Touchless sensing gesturing market

3D Models

3D modelling of the human body can be highly detailed, for Computer Generated Images (CGI) and animation for example. However, this requires substantial computing power and resources. At least for consumer electronics simpler approaches are adopted, usually based on segments of the body and the joint angles between them – a virtual skeleton. This reduces the complexity and makes the detection and modelling algorithms much faster, for example by matching movement patterns against templates for predefined control gestures. In addition to analysis of 2D images for detection of human movement, consumer electronics systems often also use a measurement of depth to facilitate 3D models.

2D Models

In general 3D models based on depth information are more accurate than models based only on 2D videos. Continuing technology development along with ever increasing computing power, however, is blurring the distinction. 2D models often comprise a set of key points on the outline of the human body, which are only allowed to deform according to defined rules. Objects detected in a sequence of 2D images can then be correlated with these templates. This approach is often used for tracking and recognising hand gestures.

Many gesture recognition algorithms are proprietary, especially those developed by large technology organisations to give commercial advantage in the market place. However, several open source approaches can be accessed for research. OpenCV[9] is a library of programming functions for real-time computer vision using graphics processing units. It supports development of gesture recognition capabilities using 2D and 3D models.

Gesture Recognition Hardware

Several device technologies are used, depending on the application, to detect human body movement, provide input for gesture recognition systems, and in some cases also provide touch tactile feedback.

9 Open CV

Handheld Controllers

When Douglas Engelbart developed the first mouse[10] in the 1960's it revolutionised the Human-Computer Interaction (HCI) experience. The mouse originally tracked movement over a surface through a rotating ball, and now does so by laser. LG's Magic Wand TV remote[11], Hillcrest Labs' Scoop remote[12], Thalmic Labs Myo armband[13], and a number of other handheld or wearable controllers, notably Nintendo's Wii Remote, use accelerometers and gyroscopes to detect human motion. Even when they operate wirelessly without a cable connection, limitations of this type of gesture recognition include the need to have another piece of equipment to interface in this way (a suitable controller may be battery powered, or need recharging, and/or could be expensive), and a constrained set of movements means a limited set of detectable gestures.

Handheld controllers are obviously remote rather than truly ***touchless*** gesture recognition systems. However some, particularly for gaming applications as introduced in Sega's Moto-cross in 1976, provide the user with the benefit of *touch* ***tactile feedback***. Other gaming examples include, simulating the feeling of motion of a virtual weapon or actually hitting a (virtual) tennis ball with weight changes and vibration.

Gloves and Wearables

Gloves equipped with many sensors to measure hand position, rotation, bending of the fingers at joints etc. allow a much richer set of human gestures can be detected. Some with limited capabilities to control personal electronics are already on the market[14,15]. Despite the appeal of futuristic control possibilities[16], having to wear special gloves to interface with machines in this way has the same limitations of handheld controllers; they can also be lost, broken and are generally size specific, so are impractical for all but the most technically demanding applications.

However, one advantage of gloves (or perhaps other wearables), like some handheld controllers, is that gloves can also generate *touch* ***tactile feedback*** for the wearer when suitably equipped with actuators or vibrators. Simulating different textures and pressures provides at least some of the tactile feedback necessary for remote manipulation of fine or complicated equipment, perhaps in dangerous and hard-to-get-to environments[17].

Cameras

Detecting human gestures at a distance, ***without touch,*** is usually achieved by processing video images. Stereo cameras augmented to measure depth can provide high accuracy 3D spatial representation of gestures. For example Microsoft's Kinect uses invisible infra-red "structured light" with a range of a few metres for X-Box gaming. eyeSight's[18] singlecue is another example of this technique developed for control of consumer electronics at a distance. Intel's RealSense™ camera and Leap Motion's Controller[19] also work in a similar way – targeted mostly towards control of computers at closer range. Microsoft has recently demonstrated algorithms for standard Kinect hardware to improve hand gesture recognition for this short-range interface to Windows computers[20].

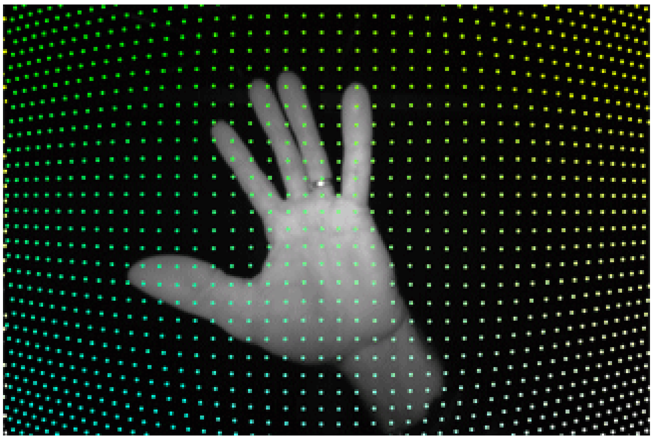


Image from Leap Motion Camera

Increasingly image-processing algorithms are allowing single 2D cameras to be used, with several computers and

10 Computer mouse
11 LG Magic Wand TV remote
12 Hill Crest Labs Scoop remote
13 Myo & Thalmic Labs
14 Beartek Gloves
15 Imogen Heap (musician)
16 Google Smart Gloves patent
17 Rice University
18 eyesight Technologies & singlecue
19 Leap Motion
20 Microsoft Handpose

tablets[21], smart TVs, and smartphones already on the market[22].

Radar

An entirely different technique for ***touchless*** detection of hand movements has recently been demonstrated by Google's Project Soli[23], which does not use conventional visible or even infra-red 2D images. Transmitting high frequency short-range radar signals and then processing the 'E-field' reflections provides a 3D spatial map with sub-millimetre resolution that allows complex gesture recognition. Implemented on a single chip may limit the range of this approach, but also makes it ideal for integration into a wide range of electronic, domestic, and automotive equipment at low cost.

Ultrasound

Elliptic Labs uses a similar approach to detect hand movements, but with ultrasound rather than Soli's E-field radar. Their software and Software Development Kits are mostly targetted towards the smartphone and tablets[24]market.

Processing Components

Several specialised components for gesture recognition systems are available separately for users own development. Examples include specialised processor chips from CogniVue (recently bought by Freescale/NXP)[25] and DepthSense sensor and camera design IP from SoftKinetic[26].

21 Qualcomm Snapdragon
22 Pantech Smartphone with eyeSight gesture recognition
23 Google Project Soli
24 ellipticlabs
25 CogniVue (bought by Freescale)
26 softkinetic

Tactile Feedback

Haptic feedback adding touch sensations to machine interfaces

The accuracy and usefulness of human gesture recognition is advancing rapidly and will continue to do so for decades to come. Issues associated with image-based systems; such as adaptability to varying lighting conditions and backgrounds, and managing unwanted objects in the field of view, are a focus of development efforts. However, only ***seeing*** and ***hearing*** limits human perception and the ability to effectively control computers, which can be a significant problem particularly in safety critical applications. Simply recognising human gestures does not necessarily provide the tactile feedback we experience, ***and value***, from physical controls such as switches and dials.

For example, if you type emails on the virtual keyboard of a tablet, phone, or touch screen computer, you'll be familiar with the need to keep looking at the screen to ensure you have "pressed" the right key (even with the benefits of predictive text). Adding the third sense of ***touch*** provides feedback that a key / button or switch has been pressed correctly. It substantially enhances perception and control. Tactile feedback is even more important in some other applications, such as vibrating the steering wheel to simulate the effect of driving over a rumble strip, which warns a distracted driver that their vehicle is drifting from its road lane. In a number of scenarios tactile feedback will be an absolute necessity to the public acceptance of ***touchless*** gesture recognition[27].

27 Georgia Tech

Haptic feedback is the sensation of touch, and is already well known in computer gaming to provide a more immersive environment, and in various scenarios such as aircraft control where user attention is critical. Recently Apple introduced their Taptic Engine, which simulates the motion of clicking a laptop track pad with a vibration. In addition to imitating the conventional "button click" of a track pad, several applications also make use of the haptic feedback: "*without looking, I could 'feel' the end of the clip*".[28]

The Apple Watch incorporates a linear actuator inside that also produces haptic feedback. "You'll feel a gentle tap on the wrist when you receive a notification, press down on the display or use Digital Touch. The Taptic Engine gives different kinds of notifications and actions… you can feel the difference between an alarm and an incoming phone call without even looking."[29]

Touch haptic effects introduced to many consumer devices

Even flat panel touch screens can use programmed interference patterns between several tiny vibrators around the edge of the glass display to produce haptic feedback at the fingertips[30] and simulate different surface textures. Samsung, Nokia Motorola, LG and HTC all use vibration haptic feedback in some of their smart phone models.

With many new consumer products now featuring haptic feedback, there is a lot of interest and numerous new applications worldwide. A number of 'standard' Application Programming Interfaces (APIs) are now available for research in the field of haptics.[31] Several of these are being used to produce tactile sensations in simulations and training for remote and keyhole surgery such as laparoscopy[32], and other medical applications.

Although tactile feedback provides a much more complete user experience, and "closes the loop" to give the ***non-visual*** cues that humans find so helpful, clearly almost all these approaches are limited by the need to be in physical contact with the haptic system. So they simply can't be used in applications based on ***touchless*** gesture recognition at a distance.

Ultrahaptics touchless haptic feedback

Providing haptic feedback without touching has been impossible until very recently. Now Ultrahaptics[33] use focussed ultrasound to provide ***touchless*** haptic feedback to recognition and control systems for hand gestures. Their Evaluation Kit includes a Leap Motion camera and gesture recognition system and is already allowing developers to experiment and generate novel haptic sensations in ***touchless*** gesture control interfaces for computers, consumer electronics and domestic appliances, and automotive dashboards to name just a few.

28 Wired
29 Apple Watch
30 Redux Sound & Touch

31 Chai3D, Open Source H3DAPI & Geomagic's OpenHaptics
32 Laparoscopic surgery tools
33 Ultrahaptics technology

Summary and Conclusions

Recognising human gestures and using them to control computers and equipment is well proven in billions of consumer and other electronic devices. The advantages of not touching the equipment are valuable, if not vital, in many use cases. So ***touchless*** gesture recognition is now a well-established market sector and an area of academic and intense commercial research by major global corporations. Of course, challenges remain in perfecting the User Experiences. They include maximizing the range and field of view, and particularly in the accuracy of detection – not only of position and movement, but more importantly in the correct understanding of the users intention.

In addition to incremental improvements from better software algorithms; and more accurate, lower cost, lower power camera and sensor hardware; tactile feedback adds another new dimension to the accuracy of ***touchless*** gesture recognition in interpreting the user’s commands and confirming the correct action to them.

For ***touchless*** hand gesture recognition, tactile feedback is the missing piece of the complete UX jigsaw. A simple comparison of some selected gesture recognition and tactile feedback systems clearly shows these fields have been mutually exclusive – until now.

System	Touchless control	Tactile feedback
Microsoft Kinect for X-Box	🗔	🖶
Microsoft Handpose for Windows	🗔	🖶
Intel RealSense	🗔	🖶
eyeSight single cue	🗔	🖶
Leap Motion	🗔	🖶
Redux S&T	🖶	🗔
Ultrahaptics*	🗔	🗔

*The Ultrahaptics Evaluation Kit incorporates Leap Motion Gesture Recognition.

For developers working at the ‘new frontier’ of gesture-driven human machine interfaces, and looking to experiment with haptic feedback, perhaps to evaluate the vast improvement that tactile feedback brings to the users, the Ultrahaptics Evaluation Kit provides the only solution for ***touchless gesture recognition*** on the market at the time of writing.

For more information on touchless haptic feedback contact the Ultrahaptics team at info@ultrahaptics.com